Passive Autonomous Acoustic Monitoring of Marine Mammals with Seagliders

David K. Mellinger and Holger Klinck
Oregon State University
2030 SE Marine Science Drive
Newport, OR 97365, USA
phone: (541) 867-0372 fax: (541) 867-3907 email: David.Mellinger@oregonstate.edu
phone: (541) 867-0182 fax: (541) 867-3907 email: Holger.Klinck@oregonstate.edu

Award Number: N00014-08-1-1082 and N00014-10-1-0387

LONG-TERM GOALS

The U.S. Navy's use of tactical mid-frequency active sonar has been linked to marine mammal strandings and fatalities [Evans and England, 2001]. These events have generated legal challenges to the Navy's peacetime use of mid-frequency sonar, and have limited the Navy's at-sea anti-submarine warfare training time. Beaked whales may be particularly sensitive to mid-frequency sonar. A mobile, persistent surveillance system that could detect, classify and localize beaked whales will help resolve the conflict between the Navy's need for realistic training of mid-frequency sonar operators and the Navy's desire to protect marine mammal populations worldwide. Underwater gliders equipped with appropriate acoustic sensors, processing, and detection systems may offer a partial solution to the problem. Acoustically-equipped Seagliders™ from the Applied Physics Laboratory of the University of Washington (APL-UW) is one such platform. A Seaglider can travel about 20 km/day through the water for a period of weeks to months, dive from the surface to 1000 m and back in a few hours, and use two-way satellite (Iridium) telemetry for data and command transfer. This makes it potentially highly useful for the long-term goal of this project, mitigating impacts of Navy operations on marine mammals.

OBJECTIVES

The objective of this effort is to develop techniques for detection and classification of beaked whale sounds for the acoustically-equipped Seaglider. Because any methods developed must run in the operational environment of the Seaglider, they must have a low average computational cost because of the limited processing power and battery life of the Seaglider. The performance of the detection and classification system will be evaluated on several field trials.

APPROACH

The detection/classification system for the Seaglider is a two-stage system. Stage 1, click detection, is operated continuously, creating a constant load, and Stage 2, classification (verification) of detected clicks, is operated only a small fraction of the time and thus can be computationally more expensive. Stage 1 is now fully implemented in the processing environment of the Seaglider. Work on stage 2 is still ongoing.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2010**	2. REPORT TYPE	3. DATES COVERED **00-00-2010 to 00-00-2010**

4. TITLE AND SUBTITLE **Passive Autonomous Acoustic Monitoring of Marine Mammals with Seagliders**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Oregon State University,2030 SE Marine Science Drive,Newport,OR,97365**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

WORK COMPLETED

Stage 1: Detection using the ERMA detector

Energy-based detection algorithms are commonly used to detect many types of sound signals, including odontocete clicks, in real time (e.g. Mellinger et al. 2004). A major advantage of such algorithms is their relatively low computational cost, as they can operate in the time domain. However, for detecting a given species of odontocete, time-domain algorithms often result in a high number of false positive detections caused by clicks of other odontocete species. The energy ratio mapping algorithm (ERMA) was developed to reduce the number of false positive detections while keeping computational cost low, as is needed for long-term (weeks to months) real-time operation with the Seaglider. ERMA was tested in several bench trials (Yack et al. 2010) and field trials (see below), and based on the results, modified and improved. The most recent version of ERMA includes a likelihood measurement for detected clicks. Detection function amplitudes of detected clicks, number of clicks, and mean inter-click-intervals (ICI) of clicks within detected bouts are used to rank [a] data files of one minute duration containing detections and [b] individual clicks within those files. This ranking is important for time-critical applications, such as mitigation of potential impacts to beaked whales during naval exercises. Data files associated with highest likelihood values as determined by the ERMA detector are analyzed by the classifier first. Once detections have been verified by the classifier, the glider is programmed to return to the surface as quickly as possible to report the presence of beaked whales back to a shore or ship-based control center. In addition, raw acoustic data snippets containing individual high-likelihood clicks are transmitted for manual verification. A ‘fixed point’ version of the ERMA based detector is also available and was implemented on another autonomous platform: the QUEphone developed by Haru Matsumoto, OSU.A manuscript (Klinck and Mellinger in review) providing an in-depth description of ERMA has been submitted to the Journal of the Acoustical Society of America and is currently under review.

Stage 2: Classification

Work on the classifier is being conducted in collaboration with Marie A. Roch, San Diego State University and Scripps Institution of Oceanography.

We developed a classification system for echolocation clicks of six species of odontocetes recorded in the Southern California Bight: bottlenose dolphins (*Tursiops truncatus*), short- and long-beaked common dolphins (*Delphinus delphis* and *D. capensis*), Pacific white-sided dolphins (*Lagenorhynchus obliquidens*), Risso’s dolphins (*Grampus griseus*), and presumed Cuvier’s beaked whales (*Ziphius cavirostris*). Echolocation clicks were represented by cepstral feature vectors (14 features) that are classified by Gaussian mixture models. A randomized cross-validation experiment (*n*-fold training/testing) was designed to provide conditions similar to those found in a field-deployed system. To prevent matched conditions from inappropriately lowering the error rate, echolocation clicks associated with a single sighting were never split across the training and test data. Sightings were randomly permuted before assignment to folds in the experiment. This allows different combinations of the training and test data to be used while keeping data from each sighting entirely in the training or test set. The system achieves a mean error rate of 22% across 100 randomized 3-fold cross validation experiments. Four of the six species had mean error rates lower than the overall mean, with the presumed Cuvier’s beaked whale clicks showing the best performance (< 2% error rate). Long-beaked common and bottlenose dolphins proved the most difficult to classify, with mean error rates of 53% and 68% respectively.

A C-code version of the classifier is now available for use in the Seaglider. Implementation of this version of the detection/classification system will be completed within the next few months. A manuscript (Roch et al. in review) providing an in-depth description of the classifier has been submitted to the Journal of the Acoustical Society of America and is currently under review.

RESULTS

1. *Field tests*

In total 4 field tests have been conducted with the PAM Seaglider to date:

- A preliminary test in the Haro Strait, WA in September 2009 (1 Seaglider),
- two tests off Kona, HI: one in October 2009 (1 Seaglider) and one in March 2010 (2 Seagliders), and
- one comprehensive test at AUTEC in June 2010 (2 Seagliders).

While the two tests off Kona, HI were primarily driven by engineering tests, the AUTEC trial was specifically designed to evaluate the detection performance and detection radius of the Seaglider. We deployed two Seagliders in the northwest corner of the AUTEC range and operated them continuously for 5 days. One glider was programmed to hold its position on top of the Whiskey 1 array while the second glider conducted East-West transects across the ‘Tongue of the Ocean’ basin. The experiment was highly successful: in total 23 encounters with beaked whales were detected by the two Seagliders. The Whiskey 1 array features a closer hydrophone spacing which allows us to locate vocalizing whales. These data will be used to estimate the distance between the glider and the whales and to evaluate the detections performance and radius of our system.

2. *Data analysis*

We are currently completing analysis of two data sets: the Hawaii 2009 data set and the AUTEC 2010 data set.

The Hawaii 2009 data set comprises 131 GB of acoustic data, recorded during 85 dives of the Seaglider. The entire data set is currently being manually analyzed by an experienced analyst and annotated to indicate which species are present when. The annotated data set will provide ground-truth data to evaluate the performance of beaked whale detectors and classifiers. Furthermore, this data set will allow us to generate a Seaglider-specific beaked whale Gaussian mixture model to increase the performance of the classifier. We intend to finish this analysis by end of November 2010.

During the Hawaii experiments we flew over a HARP deployment site off Kona on a regular basis. We intend to conduct, in collaboration with Scripps (M. Roch, J. Hildebrand, S. Baumann) a comparison of the two data sets.

The AUTEC 2010 glider data analysis is complete: the data have been manually screened for beaked whale echolocation clicks. In total 23 encounters were identified. All encounters were detected by the ERMA-based detector during the trail in near real-time, a feat which we consider one of our best

successes. We are currently waiting for release of the data set from the AUTEC system hydrophones to determine the position of the beaked whales and to evaluate the detection radius of the Seaglider.

IMPACT/APPLICATIONS

It is hoped that a “beaked whale Seaglider” will be useful for the conservation of cetaceans by revealing their presence before and during Navy operations, thus allowing for the use of mitigation measures to prevent harm to them. It is also hoped that Seagliders equipped with the detection technology developed here will be more broadly useful, perhaps for monitoring marine mammal population changes, studies of the seasonal distribution of marine species, marine mammal behavioral observation, and other applications that we have not yet anticipated.

RELATED PROJECTS

We are closely collaborating with the project “Passive Autonomous Acoustic Monitoring of Marine Mammals: System Development using Seaglider”, with PIs Neil Bogue and Jim Luby of the Applied Physics Laboratory, University of Washington. The Bogue/Luby group is (1) developing and testing anew processor architecture for the Seaglider, (2) developing and testing an associated new acoustic recording system for the Seaglider, (3) leading the fieldwork to test deployments of the “beaked whale Seaglider”. We are primarily developing algorithms for detecting beaked whales from the Seaglider and implementing these algorithms in the Seaglider’s processing environment, while UW is developing hardware, building the acoustic processing environment, and operating the Seaglider.

The ONR-funded project “Acoustic Float for Marine Mammal Monitoring” (P.I. Dr. Haru Matsumoto, OSU) is also using the ERMA detector described above. It is implemented differently in the two projects, mainly because of different processor architectures used in the PAAM boards of each instrument.

PUBLICATIONS

Articles
Klinck, H. and D.K. Mellinger. In review. The Energy Ratio Mapping Algorithm (ERMA): a tool to improve the energy-based detection of odontocete clicks. Submitted to the Journal of the Acoustical Society of America.

Roch, M.A., H. Klinck, D.K. Mellinger, S. Baumann-Pickering, M.S. Soldevilla, M. McDonald, and J.A. Hildebrand. In review. Classification of odontocetes in the Southern California Bight through the use of echolocation clicks. Submitted to the Journal of the Acoustical Society of America.

Sagen, H., S. Sandven, A. Beszczynska-Moeller, O. Boebel, T.F. Duda, L. Freitag, J.C. Gascard, A. Gavrilov, C.M. Lee, D.K. Mellinger, P. Mikhalevsky, S. Moore, A.K. Morozov, M. Rixen, E. Skarsoulis, K. Stafford, E. Tveit, and P.F. Worcester. 2009. Acoustic technologies for observing the interior of the Arctic Ocean. Proc. OceanObs'09, 21-25 September 2009, Venice. 4 pp.

Yack, T., Barlow, J., Roch, M. A., Klinck, H., Martin, S., Mellinger, D. K., and Gillespie, D. (2010): Comparison of beaked whale detection algorithms. Applied Acoustics 71: 1043-1049.

Abstracts
Mellinger, D.K. 2010. Detecting sequences of calls. J. Acoust. Soc. Am. 127(3): 2005(A).
Olmstead, T.J., M.A. Roch, P. Hursky, M. B. Porter, H. Klinck, D.K. Mellinger, T. Helble, S.S. Wiggins, G.L. D'Spain, and J.A. Hildebrand. 2010. Autonomous underwater glider-based embedded real-time marine mammal detection and classification. J. Acoust. Soc. Am. 127(3): 1971(A).

Mellinger, D.K., H. Klinck, N.M. Bogue, J.C. Luby, W.A. Jump, J.M. Pyle, G.B. Shilling, T. Litchendorf, A.S. Wood. 2010. Ocean gliders for acoustic observation of marine mammals. Invited presentation. Abstract BO44B-01, Ocean Sciences Meeting, Portland, Feb. 22-26, 2010, p. 93.

Mellinger, D.K. 2009. Automatic detection for long-term monitoring of marine organisms. Book of abstracts, ONR Marine Mammal Program Review, Dec. 7-10, 2009, Alexandria, VA, pp. 54-55.

Bogue, N.M., J.C. Luby, W.A. Jump, J.M. Pyle, G.B. Shilling, T. Litchendorf, A.S. Wood, D.K. Mellinger, H. Klinck. 2009. Passive acoustic monitoring using Seaglider: initial deployments. Book of abstracts, ONR Marine Mammal Program Review, Dec. 7-10, 2009, Alexandria, VA, pp. 52-53.

Matsumoto, H., C.D. Jones, D.K. Mellinger, and R.P. Dziak. 2009. Acoustic float for marine mammal monitoring. Book of abstracts, ONR Marine Mammal Program Review, Dec. 7-10, 2009, Alexandria, VA, pp. 70-71.

Roch, M., Y. Barkley, S. Baumann-Pickering, J.A. Hildebrand, P. Hursky, H. Klinck, D.K. Mellinger, B. Patel, M. Porter, S. Qui, S. Rankin, M. Soldevilla, and S.M. Wiggins. 2009. Acoustic detections and how to manage them. Book of abstracts, ONR Marine Mammal Program Review, Dec. 7-10, 2009, Alexandria, VA, pp. 62-63.

Klinck, H., D.K. Mellinger, N.M. Bogue, J.C. Luby, W.A. Jump, J.M. Pyle, and G.B. Shilling. 2009. Autonomous passive acoustic monitoring of marine mammals using the Seaglider: onboard real-time detection and classification of target signals. Book of abstracts, ONR Marine Mammal Program Review, Dec. 7-10, 2009, Alexandria, VA, p. 86.

Mellinger, D.K., D. Gillespie, C. Clark, A. Thode. 2009. Signal processing overview. Presentation Abstracts, Acoustic Monitoring and Mitigation Systems: Status and Applications for Use by Regulated Offshore Industries, Minerals Management Service, Nov. 17-19, 2009, Boston, pp 14-15.

Tina M. Yack, Jay Barlow, Marie A. Roch, Holger Klinck, Steve Martin, David K. Mellinger, Douglas Gillespie, Comparison of beaked whale detection algorithms, Applied Acoustics, Volume 71, Issue 11, Proceedings of the 4th International Workshop on Detection, Classification and Localization of Marine Mammals Using Passive Acoustics and 1st International Workshop on Density Estimation of Marine Mammals Using Passive Acoustics, November 2010, Pages 1043-1049